DRAFT Preliminary Review: Navy Groundwater Flow Model for the Navy Red Hill Facility

By:

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Technical subject matter experts
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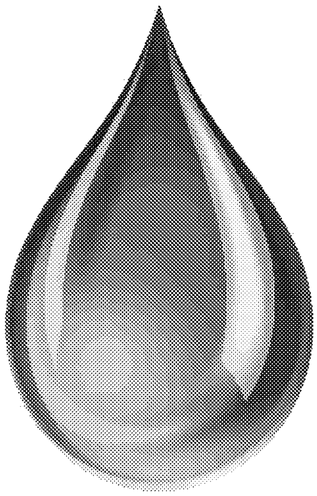
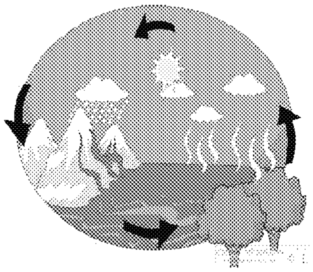
One Overarching Goal



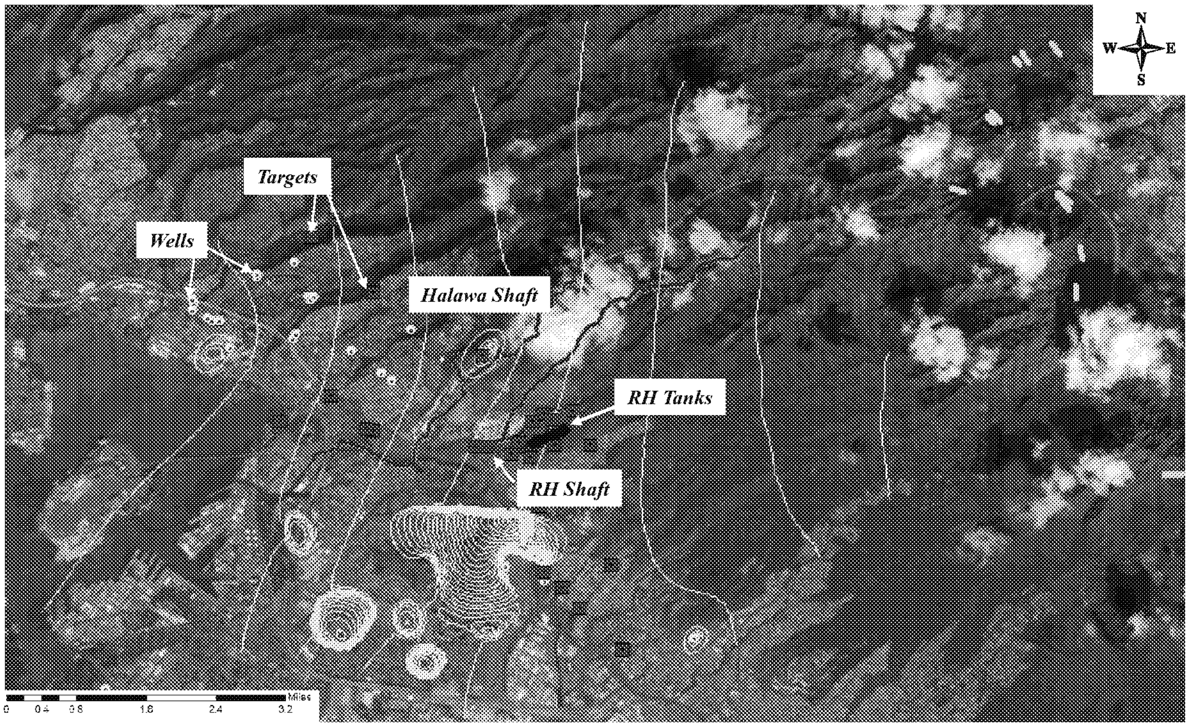
- The purpose of this deliverable is to refine the existing groundwater flow model and improve the understanding of the direction and rate of groundwater flow within the aquifers around the Facility (AOC, 2015)
  - *To do this, the underlying geologic conditions must be refined and better understood in light of new data not available to prior modeling*

The Navy Has Delivered Multiple Models



- Key review questions:
  - Do the models represent local heads?
  - Do the models represent gradients?
  - Do the models reflect transient aspects?
    - Pumping from Red Hill & Halawa shafts
    - Monitoring well "groupings"
  - Do transient simulations better past models?
  - Are models consistent with geochemistry?
  - Are models consistent with COCs?
  - Are models parameters justified?
- Will the model inform risk estimates?
  - Most uncertain aspect is NAPL
    - Where is it presently & in what state?
    - How far/fast could releases travel?
  - Is there any basis for down-scaling?

General Area/Model Map
(Halawa Shaft On, RH Shaft Off)



Current Model Matrix - 1

Run ID	Description	Significant Features	Calibration and Verification Summary and Conclusions	Application Summary and Conclusions
51	Homogeneous basalt with CSM saprolite	Evaluate regional flow behavior.	—	Water from beneath the Facility is captured by Red Hill Shaft when it is pumping.
51a	Limit horizontal anisotropy (3:1)	Assumed to be a conservative assumption and used in previous modeling efforts.	High head values were simulated low. There was less simulated water level difference in wells across Kalihi Valley, Moanalua Valley, Red Hill, North and South Hālawa Valleys, and Waimalu Valley. Pumping response to Red Hill Shaft was generally underpredicted (higher simulated connectivity), and pumping response to Hālawa Shaft was generally overpredicted (lower simulated connectivity).	Migration from the Facility was to the west and then NW when Red Hill Shaft is off, with some tracks migrating toward Hālawa Shaft and others toward Pearl Harbor.
51b	10:1 anisotropy	Evaluate impact of possible higher horizontal anisotropic conditions.	Model #5 to captures the simulated water level differences from SE to NW across valleys better. The model provided NW directional regional head gradients. Pumping response to Red Hill Shaft was generally underpredicted (higher simulated connectivity), and pumping response to Hālawa Shaft was generally overpredicted (lower simulated connectivity).	Migration from beneath the Facility was still to the west and then turned NW when Red Hill Shaft is off. The elongated capture zone of Hālawa Shaft caused by the larger anisotropy intercepted water from the Facility.
51c	Zoned along ridges	Evaluate impact of flexibility along each hill.	Simulated water level difference statistics were better than Model #51a and similar to Model #51b. Model #51c better captures drawdown behavior than Model #51a for Red Hill Shaft, but Hālawa Shaft connectivity was still too large.	Migration from beneath the Facility was to the west and continued toward Pearl Harbor, being intercepted also by wells 2253-39 and ʻAiea Hālawa Shaft. Migration behavior is different from that of previous models.
51d	Calibrate on anisotropy	Evaluate what value of anisotropy best captures regional water level conditions (17.54 for this model).	PEST would gravitate toward values between 17 and 18 with vertical hydraulic conductivity of 40–70 ft/d during the different calibration runs. The model provided good calibration to regional water levels and differences. Model #51d provides a better match to Red Hill Shaft pumping than Model #51a or Model #51b, but still has too much connectivity between Hālawa Shaft and the Facility.	Migration behavior is similar to model with less (10:1) anisotropy. Larger anisotropy caused capture zones of wells and shafts to be wider.
51e	Zoned along ridges and within valleys	Evaluate impact of additional zonation since zoned conditions of Model #51c did not adequately distinguish itself from the average conditions of homogeneous Model #51a.	Additional zonation from Model #51c can capture regional water level conditions and connectivity between Red Hill Shaft, Hālawa Shaft, and the Facility. Also, the model provided relatively flat gradients at Red Hill due to a damming effect.	Migration from the Facility was to the west and continued toward Pearl Harbor, to discharge into Pearl Harbor Springs when Red Hill Shaft was not pumping.

Run ID	Description	Significant Features	Calibration and Verification Summary and Conclusions	Application Summary and Conclusions
58	Coastal marine discharge variability	Evaluate impact of variability in discharge to ocean and Pearl Harbor.	Calibration to regional water levels and water level gradients was good. Connectivity between the Facility and Hālawa Shaft was overpredicted, although less than for Model #51a.	More discharge to Pearl Harbor than the ocean boundary does not impact the migration behavior of water from beneath the Facility or of the source water zones of key supply shafts.
59	Lateral inflow from SE	Evaluate conceptual model of flow across valleys from Kalihi Valley to Pearl Harbor.	Larger volumes of flow in the domain causes higher flow gradients. During calibration, higher K-values that flatten the gradients resulted in a poorer fit of the drawdown impacts.	Source water zones of Red Hill Shaft and Hālawa Shaft shift to the east. However, the migration of water from the Facility is not significantly impacted by lateral SE inflow.

K hydraulic conductivity

Current Model Matrix - 2

Run ID	Description	Significant Features	Calibration and Verification Summary and Conclusions	Application Summary and Conclusions
51a–51e	Collective evaluation of the homogeneous models	Evaluate impact of different homogeneous conceptualizations on calibration and migration behavior of water from the Facility.	Collectively, the simulations indicate a basalt anisotropy of about 17 to capture regional water levels and differences. Offshore outflow was larger compared to Pearl Harbor outflow for the higher anisotropy cases (still significantly smaller than other outflows). Zonation of Model #51e provided best fit to all calibration metrics.	Flow occurs down Red Hill ridge from areas of recharge to areas of discharge (wells, springs, Pearl Harbor, or the ocean). Water from the Facility is captured by Red Hill Shaft when it is pumping; however, the different uncertainties evaluated here provide different migration behavior when Red Hill Shaft is not pumping. Zonation of Model #51e altered flow paths and travel times most significantly compared to average homogeneous basalt models.
52	Alternate saprolite	Test impact of alternate saprolite extent and depth below water table.	The calibration metrics were not impacted by the range of simulated uncertainty in extent and depth of saprolite beneath South Hālawa Valley.	Results are almost identical to Model # 51a, which was used as the basis for this simulation, with only slight differences in travel times. Saprolite extent and depth did not impact calibration or flow paths of concern within the uncertainty limits tested (20–40 ft) considering that the basalt extends to depths of 500–800 ft beneath it.
53	Heterogeneous basalt	Evaluate impacts of regional- and local-scale heterogeneities using pilot points using random initial parameter distributions.	A heterogeneous model can capture regional water level conditions and connectivity between Red Hill Shaft, Hālawa Shaft, and the Facility.	Migration behavior was similar to that of many other models when Red Hill Shaft was not pumping, with some water from the Facility turning toward Hālawa Shaft, while the rest flowing toward Pearl Harbor Spring at Kalauao, being intercepted by wells 2255-39 and 'Aiea Hālawa Shaft.
54	Heterogeneous basalt	Evaluate alternate impacts of regional- and local-scale heterogeneities using pilot points using initial parameter distributions that block downhill flow from the Facility.	A heterogeneous model can capture regional water level conditions and connectivity between Red Hill Shaft, Hālawa Shaft, and the Facility. The damming effect of water behind Red Hill Shaft was not created, even with starting conditions favorable to such conditions.	Migration behavior was different from all other models when Red Hill Shaft is not pumping, with water from the Facility migrating due NW being captured by Hālawa Shaft. Thus, it was possible to calibrate a model to available data with flow from the Facility toward the NW as per one of the conceptualizations of the flow system.
55	Conceptual clinker zone	Evaluate impact of fast-flow pathway in groundwater beneath the Facility.	PEST would gravitate toward a clinker K-value of about 30,000 ft/d. Red Hill Shaft pumping changes are better predicted at the Facility, indicating better representation of that connectivity.	Flow was controlled to a certain extent by fast flow pathways; however, travel times were sensitive to clinker porosity.
56	Structural alterations to tuff cones	Evaluate impact of a damming effect of tuff cones on flow down Red Hill.	Water level gradients were more to the NW than the homogeneous model (Model #51a), but reverse gradients were not created.	Flow from the Facility was also more to the NW than the homogeneous model (Model #51a), with water from Red Hill Shaft location also migrating to Hālawa Shaft when Red Hill Shaft was off.
57	Recharge uncertainty	Evaluate impact of applying drought condition recharge inflow.	Calibration to regional water levels and water level gradients was good. Connectivity between the Facility and Hālawa Shaft was overpredicted, although less than for Model #51a.	Flow from the Facility and source water zones of Red Hill Shaft and Hālawa Shaft were not significantly impacted, and uncertainty in recharge did not translate to uncertainty in migration behavior.

Groundwater Flow Model Report, Red Hill Bulk Fuel Storage Facility, March 2020

Model Pumping Conditions

(aka, stress periods)

General Calibration – Amalgamated Data

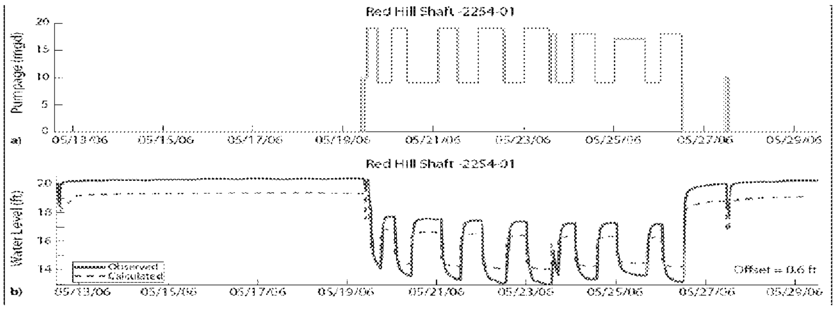
Stress Period #	Time (d)	Description
1	1	Steady state, Red Hill Shaft pumping 7.57 mgd, Hālawa Shaft pumping 6.57 mgd
2	16	Transient response to shutting off Red Hill Shaft
3	17	Steady state, Red Hill Shaft pumping 0 mgd, Hālawa Shaft pumping 6.33 mgd
4	32	Transient response to shutting off Hālawa Shaft

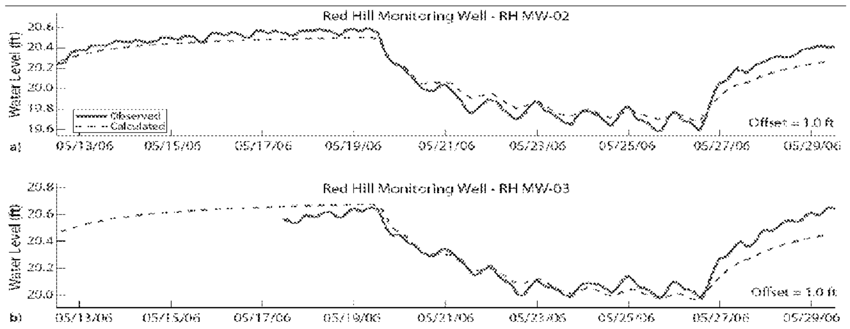
Verification Calibration – Calendar-Specific Data

Stress Period #	Start Date	End Date	Duration (days)	Total Days	Red Hill Shaft Pumping (mgd)	Hālawa Shaft Pumping (mgd)
1	10-Jan-18	15-Jan-18	Steady state	0	0	6.3131
2	15-Jan-18	19-Jan-18	4.4236	4.4236	7.6846	6.3146
3	19-Jan-18	27-Jan-18	8.0694	12.4931	4.1792	6.1997
4	27-Jan-18	6-Feb-18	9.4965	21.9896	3.6849	0
5	6-Feb-18	10-Feb-18	4.4931	26.4826	3.6044	12.0889

The Primary Issue with Prior Model

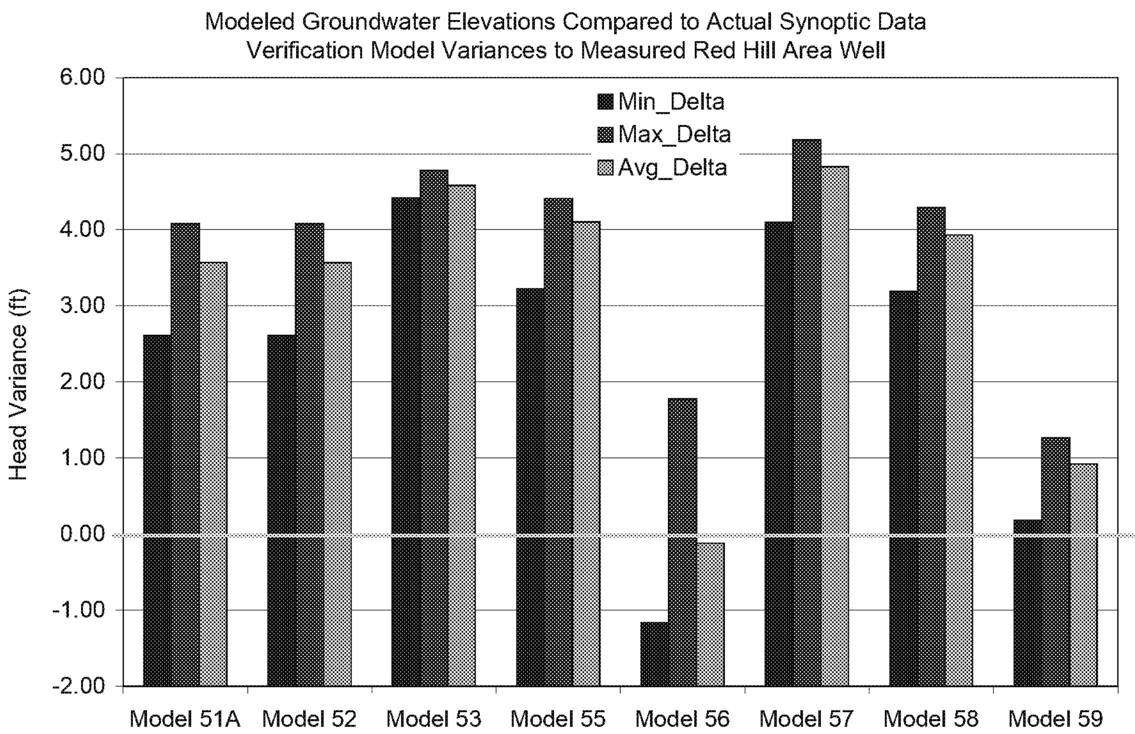
(calibrated to drawdown, but not to heads; complexity)



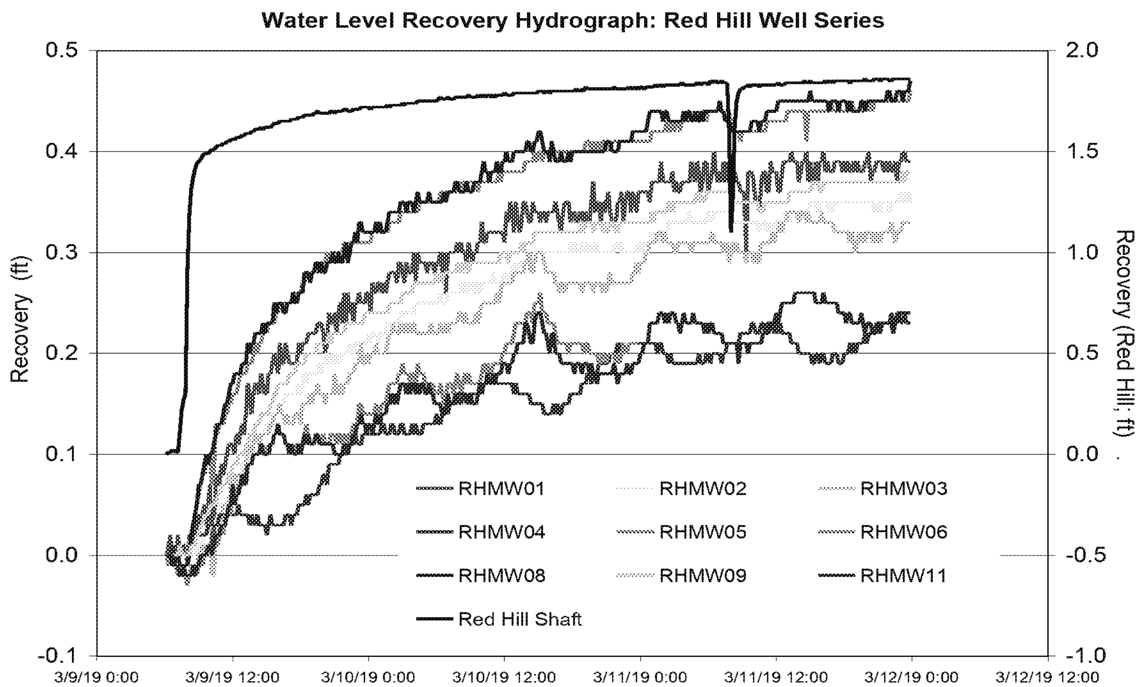


Kolja Rotzoll and Aly I. El-Kadi, 2007

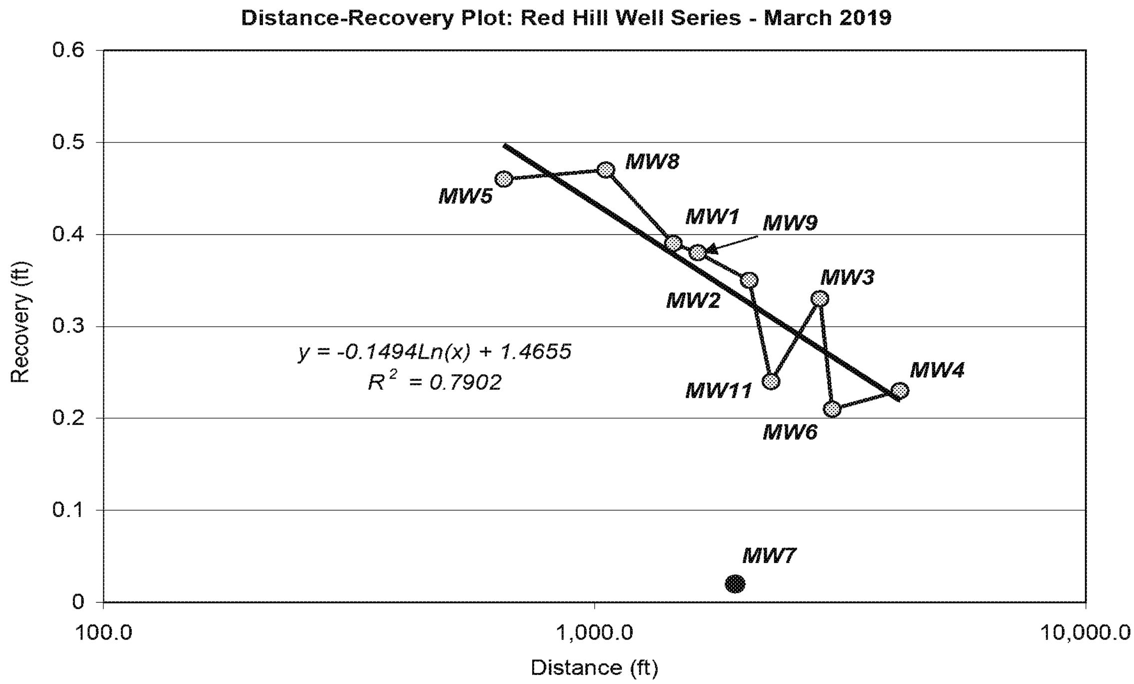
GW Elevation Variance – Transient Models



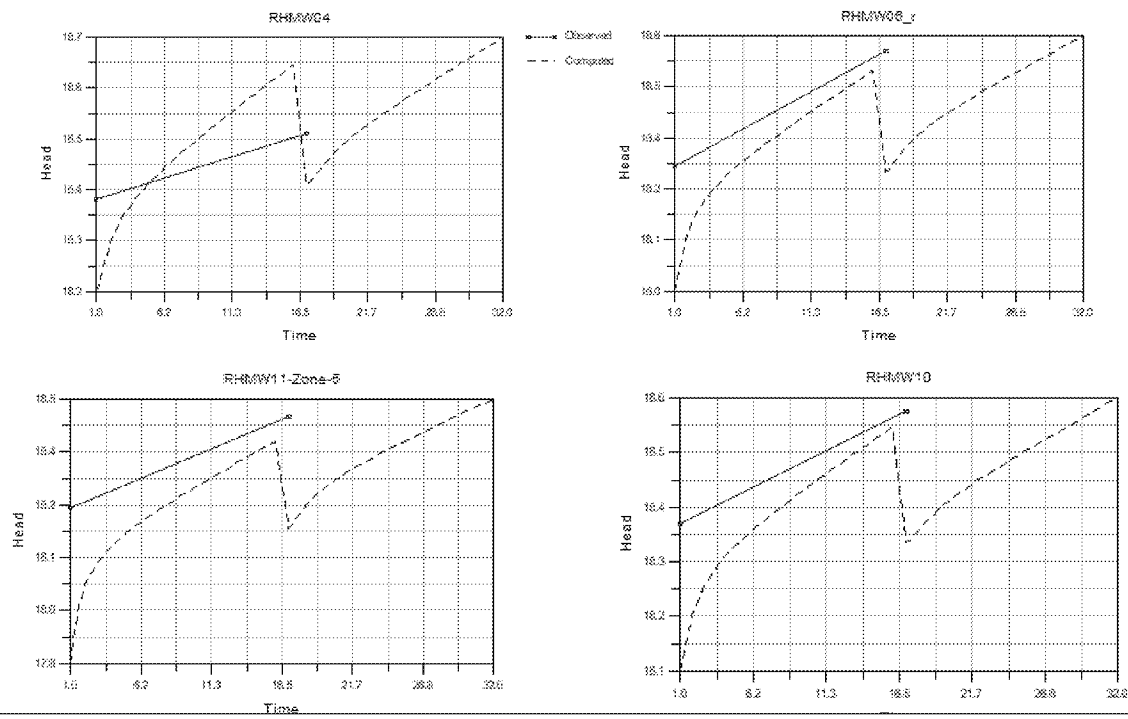
Well Response Differs in Various Wells



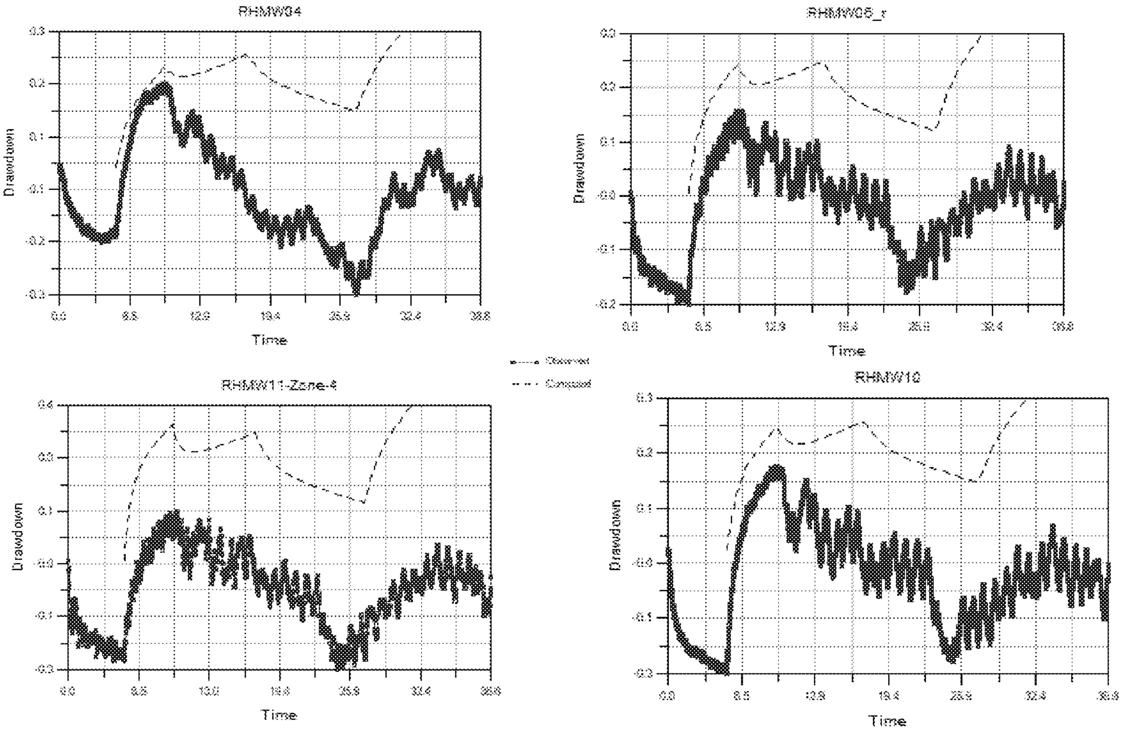
Non-Uniform Distance Drawdown Behavior



Example Hydrographs; M51a Base Case



Example Hydrographs; M51a Verification

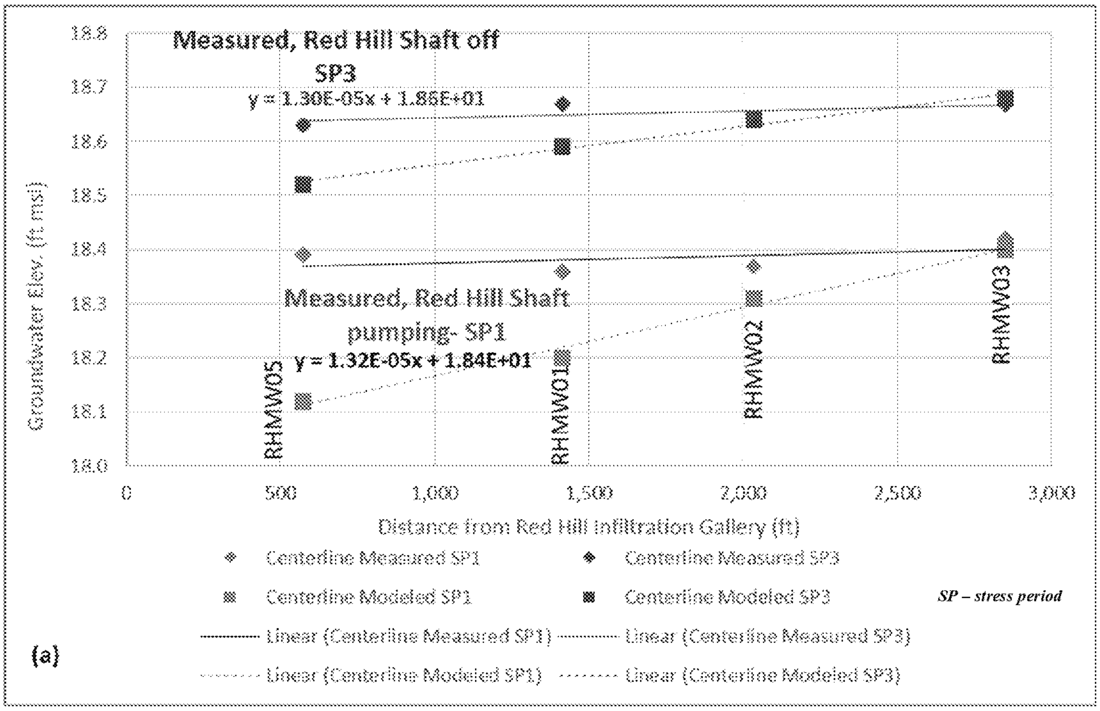


Prior Key Parameters v. Navy Models

	Oki, 2005			Navy GWFM - avgs		
Hydrostratigraphic Unit	Kv	Kt	Kl	Kv	Kt	Kl
Volcanic-rock aquifer	7.5	1,500	4,500	65	1,000	2,999
Caprock, upper-limestone unit	25	2,500	2,500	0.01	500	500
Caprock, low-permeability unit						
Above Waianae Volcanics	0.3	0.3	0.3	0.01	1	1
Above Koolau Basalt, west of Waiawa Stream	0.01	0.01	0.01	0.01	1	1
Above Koolau Basalt, east of Waiawa Stream	0.6	0.6	0.6	0.01	1	1
Valley-fill barriers	0.058	0.058	0.058	0.01	1	1

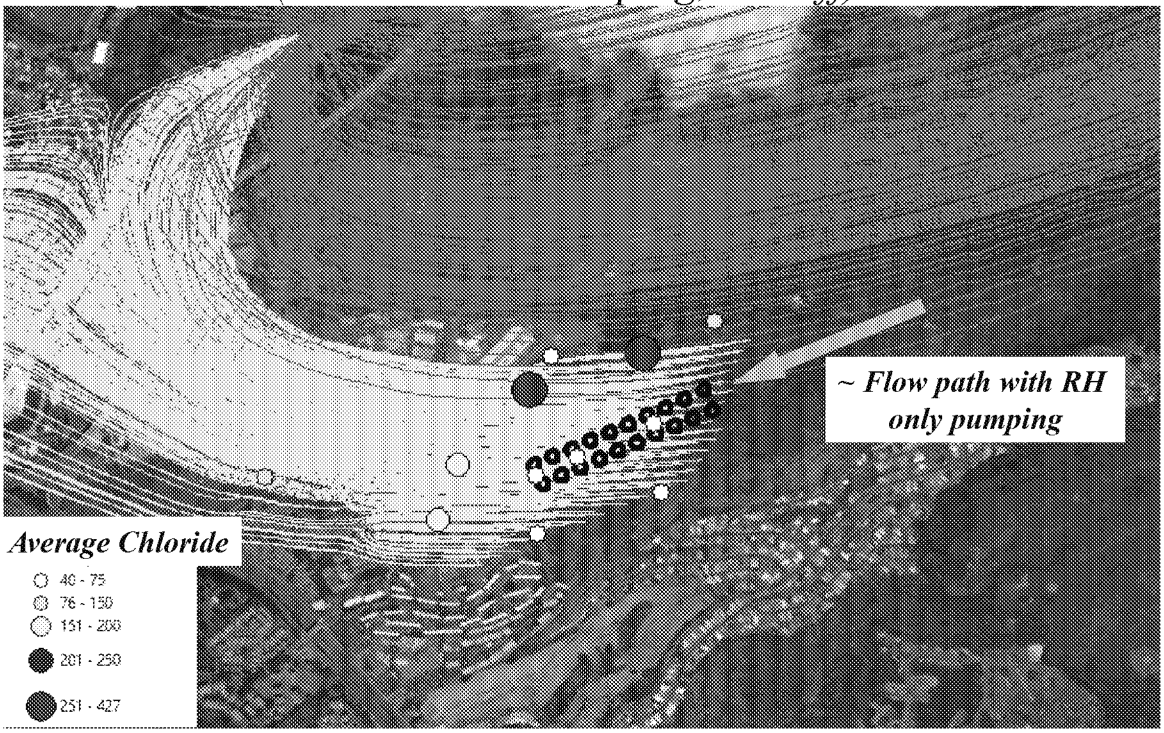
Modeled Gradients Are Too Large

(Red Hill area, no gradient change under pumping)

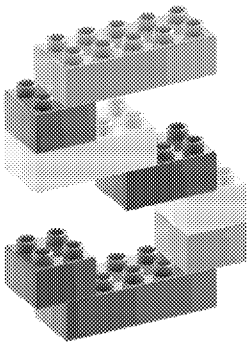


Chloride in Groundwater with Model 51A Paths

(BWS Halawa Pumping, RH Off)

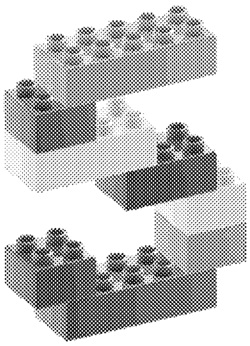


DOH Model Review Observations



- GWFMs have trouble matching heads, diminishing reliability
  - In transient verification runs
  - Same issue as in prior modeling (2007)
- GWFMs use atypical parameters for Hawaii aquifer
  - If retained, in depth justification needed
- GWFMs do not utilize geologic details – SSPA work
  - Impact of geologic heterogeneity needs further evaluation
- GWFMs do not comport with geochemistry
- GWFMs do not comport with well responses
- GWFMs capture zones not supported by field data at pumping rates similar to those modeled
  - Parameters selected overestimate capture potential
  - Gradient issues & complexity not covered
- As the GWFM's currently stand, they are not reliable
  - For CF&T, risk analyses and mitigation decisions

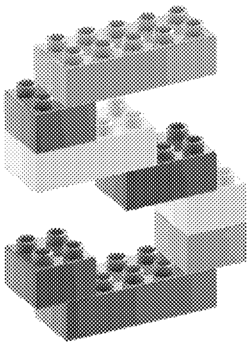
Broad CSM Observations



- The CSM is the basis for the GWFMs
  - Contains non-conservative & undemonstrated conclusions. Agency technical concerns remain unaddressed[1,2]

    [1]Whittier, Robert, Groundwater Flow Paths Report, DOH, July, 2019
    [2]DOH CSM Comments March, 2020
- The field and laboratory data collected are of good quality
  - But spatial density is a highly limiting factor, especially in near field areas
- Distal detections should not be eliminated
  - Multiple LOEs indicate probable validity
    - Co-located, detections of other fuel constituents
  - Little natural organic carbon in these aquifers
    - i.e. TPH polars likely originate from fuel
- Thermal interpretations of LNAPL location unsupported
  - The are no confirmatory in situ data
  - No other confirmatory sites

Broad CSM Observations (continued)



- Holding model & LNAPL approaches are non-conservative
  - Underlying petrophysical data are flawed, as noted in 2018 regulatory comments
  - Model geometry unsubstantiated by data
  - Mass already present and nature and extent of historic releases are unknown
  - Capture of LNAPL releases is a *transient* issue, cannot be addressed with steady-state approaches